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Hydrogeomorphic Approach to Assessing Wetland Functions: Guidelines for Developing Regional Guidebooks

Chapter 4
Developing Assessment Models

R. Daniel Smith and James S. Wakeley

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Preface

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4 Developing Assessment Models

Introduction

This chapter introduces the steps required to develop initial assessment models for the Hydrogeomorphic (HGM) Approach (Smith et al. 1995). These steps, shown in Figure 4-1 include the following: (a) select wetland functions, (b) define wetland functions and an independent, quantitative measure of function, (c) select and define model variables, (d) identify measures of model variables, (e) transform measures into model variable subindices, and (f) develop aggregation equations for deriving functional indices. Later chapters consider other steps related to the development of assessment models, including identification of reference wetlands (Chapter 3), collection and management of reference data (Chapter 5), analysis of reference data and calibration of assessment models (Chapter 6), and verification, field testing, and validation of models (Chapter 7).

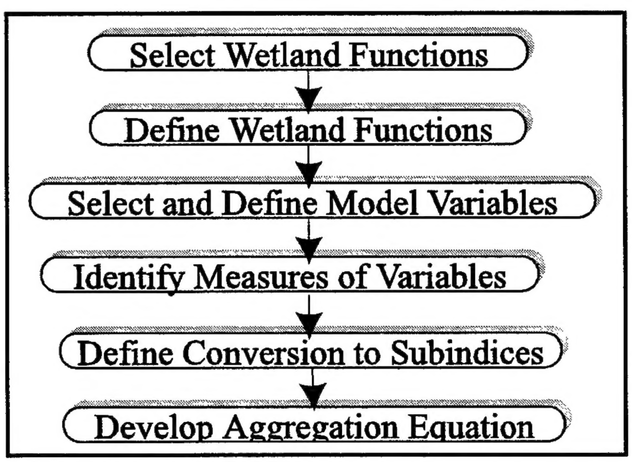

Figure 4-1. Steps in developing the initial assessment model

A model is a simplified representation of a system that attempts to explain how the system functions and predict how it will respond to different conditions. Models range in complexity from paper airplanes and maps to three-dimensional numerical simulations of ocean currents and weather (Hall and Day 1977; Jørgensen 1988; Mitsch, Straškrabe, and Jørgensen 1988). This reflects the inherent range of complexity in systems or the level of detail at which information is being gathered about a particular system.

In constructing models, the objective is to produce a representation that mimics specific attributes and processes of the system at the level of accuracy and precision required by the target application. Simplification is a legitimate and necessary part of model development that is achieved only at the cost of reduced accuracy and precision (Levins 1966). The degree of simplification is dictated by the characteristics of the system and the way in which the model will ultimately be applied. The skill of the modeler is manifested in deciding which components of the system to include and which components to ignore. An appropriate model is not necessarily complex. Rather, it is one that can be applied efficiently while providing results at the required level of accuracy and precision (Skellam 1969).

In the HGM Approach, assessment models are simple representations of the functions performed by wetland ecosystems. The purpose of the models is to estimate the magnitude at which a wetland performs a function relative to similar wetlands in the region. In the model, variables represent the characteristics and processes of the wetland ecosystem and the surrounding landscape that influence the ability of the wetland to perform a function. Model variables are quantitatively measured or qualitatively estimated using standardized sampling protocols that are easy and rapid to apply (see Chapter 5). These measures of model variables are transformed into model variable subindices scaled from 0 to 1, and then aggregated using a simple weighted equation to produce a Functional Capacity Index (FCI) ranging from 0 to 1. This type of model has been variously described in the literature as multiple-criterion models (Smith and Theberge 1987), composite indices (Ott 1978), or multimetric models (Barbour, Stribling, and Karr 1995). They have been used extensively in environmental impact assessment (U.S. Fish and Wildlife Service 1980, 1981; Westman 1985).

Selecting Wetland Functions

Basis for the functional approach

In the wetland regulatory arena, the basic approach to assessing project impacts has traditionally been to compare the ability of a wetland to perform specific wetland functions under pre- and post-project conditions (Corps Regulatory Program Regulations (33 CFR Sections) and U.S. Environmental Protection Agency (EPA) 404(b)(1) Guidelines (40 CFR Section 230)). The 1990 Mitigation Memorandum of Agreement between the EPA and Department of the Army supported this functional approach by stating that assessment

techniques should "fully consider the ecological functions included in the Guidelines." A generic suite of wetland functions "important to the public interest" is discussed in the Corps Regulatory Program Regulations and EPA 404(b)(1) Guidelines. The functions include food chain production; provision of habitat for nesting, spawning, and rearing; maintenance of natural drainage characteristics; protection from erosion and storm damage; storage of floodwaters; groundwater discharge and recharge; and water quality improvement.

It has often been stated that not all wetlands perform all functions in the same way, or to the same degree or magnitude. One of the advantages of the HGM Approach is that by classifying wetlands using hydrogeomorphic characteristics (Brinson 1993), it is possible to select a "custom" suite of functions specific to each regional wetland subclass. The remainder of this chapter discusses issues related to the selection of functions, including review of existing literature, ecosystem context of wetland functions, role of value in assessment, hierarchy of functions, model resolution, and availability of time and resources.

Review of the literature

The first step in selecting functions for a particular regional wetland subclass is to review the national and regional guidebooks being developed as part of the HGM Approach (e.g., Brinson et al. 1995, Ainslie et al. in preparation, Gilbert, in preparation; Sheehan, in preparation; Rhinehardt, in preparation; Hauer, in preparation, and Vinzant, in preparation). These documents define and describe the suite of wetland functions selected for specific regional wetland subclasses, outline the criteria used in the selection process, discuss why each function was selected, and provide references to literature and other sources of information used in the selection process. These descriptions are important because they facilitate the exchange of information among Assessment Teams (A-Teams) and promote consistency and quality in regional guidebook development.

In addition to the literature related to the HGM Approach, other assessment methods should be reviewed. Methods developed by Larson (1976), Reppert et al. (1979), Euler et al. (1983), Hollands and Magee (1985), Ammann, Franzen, and Johnson (1986), Adamus and Stockwell (1983), Adamus et al. (1987), U.S. Army Corps of Engineers (1988), Ammann and Stone (1991), Bartoldus, Garbisch, and Kraus (1994), and Miller and Gunsalus (1997) define and describe numerous wetland functions, and provide different perspectives on the selection of those functions. Furthermore, the wetland literature contains a number of models developed for different wetland attributes and processes that may be useful in identifying important wetland functions or potential model variables (Mitsch, Straškrabe, and Jørgensen 1988). Before any of the functions discussed in a national or regional guidebook or other assessment method is adopted, the rationale used to select and justify the function should be critically reviewed to determine whether it is appropriate for the guidebook under development.

The ecosystem context

One of the potential problems with a function-by-function approach to wetland assessment is the tendency to think of functions as things that can be assessed, mitigated, restored, enhanced, or traded independent of their wetland ecosystem context. A fundamental assumption of the HGM Approach is that, even though it is functions that are being assessed, the underlying objective is to determine the impact of the project on the overall integrity and health of the wetland ecosystem (Schaeffer, Herricks, and Kerster 1988; Rapport 1989; Noss 1990; Karr 1991; Kay 1991; Costanza, Norton, and Haskell 1992; Steedman 1994). In order to achieve this goal it is critical that the A-Team select a suite of functions that represents the range of ecosystem characteristics and processes necessary to maintain the integrity and health of the wetland.

Selecting a representative suite of functions is also critical to the use of reference standard wetlands as the standard of comparison for calibrating functional indices. As discussed in Chapter 3, reference standard wetlands are the wetlands that achieve the highest sustainable level of function concurrently across the suite of functions. If the suite of functions selected represents the range of attributes and processes necessary to maintain a healthy wetland ecosystem, then assessment results will provide a good measure of overall ecosystem health. However, if the suite of functions is not representative, it is possible for functional indices to remain high while the overall health and integrity of the wetland ecosystem deteriorate.

The importance of the representative suite of functions and the use of reference standard wetlands to calibrate functional indices are especially crucial when dealing with wetlands that have been subjected to disturbance and alteration. In disturbed wetlands or wetlands managed to maximize specific functions or species (e.g., green tree reservoirs), functional indices are often relatively low, reflecting a departure from the conditions exhibited in healthy wetlands (i.e., reference standard wetlands). Typically, disturbed or managed wetlands perform one function at levels that exceed the level exhibited in reference standard wetlands. Usually, however, this level of performance cannot be sustained over the long term, and is accompanied by a reduction in the level of performance across the remaining suite of functions. There is a strong temptation under these circumstances to adopt a new standard for calibrating functional indices and rationalize its use based on the fact that since disturbed, altered, or managed wetlands are all that remain, they are valuable and standards must be revised to protect them. It may indeed be true that since disturbed, altered, or managed wetlands are the only wetlands around, they are valuable. However, this is a value judgment that should not affect the assessment of how wetlands function. Redefining the standard of comparison moves assessment into a subjective arena where functional indices are dictated by the most "valued" or only functions being performed, rather than by a suite of functions that reflect the overall integrity and health of the wetland ecosystem. It initiates the precedent of developing standards of comparison for specific situations, which guts the whole point of the HGM Approach (i.e., to determine the capacity of a wetland to function in the context of similar wetlands in a region).

Questions concerning the value and protection of certain wetlands should be addressed in the policy arena, not at the assessment level (see next section).

The role of value

Value is defined as the relative importance of something to an individual or group (Smith et al. 1995). The HGM Approach is not designed to assess the value of wetland functions. It is designed to supply the technical information necessary to determine how a project will impact the way a wetland functions. This information can then be used to support the explicit or implicit value judgments that inevitably take place in the permit review process.

Even though the HGM Approach does not assess or assign value, it is important to recognize that in selecting functions there may be an implicit bias to favor wetland functions with direct and immediate benefits. For example, floodwater storage is one of the most commonly identified wetland functions. This is because it is widely recognized as a result of televised images of flood victims and reports of large economic losses incurred as a result of flooding. At the other end of the spectrum, however, are wetland functions that provide important but less direct and immediate benefits. Wetlands, for example, function as carbon sinks by removing carbon dioxide from the atmosphere and storing it in living and dead plant biomass (Raich and Schlesinger 1992). This function has been implicated in the stabilization of atmospheric greenhouse gases at a global scale (Gorham 1990), but since the benefits are less direct and immediate, or perhaps because the mechanisms are poorly understood, it is rarely selected as a function for assessment. The purpose of this discussion is not to discourage the selection of functions that provide direct and immediate benefits, but rather to encourage consideration of wetland functions whose benefits, although less direct and immediate, may play an important role in maintaining the integrity and health of the wetland ecosystem and the larger surrounding systems.

The hierarchy of functions

The HGM Approach defines wetland functions as the activities that normally occur in wetland ecosystems, or simply, the things that wetlands do (Smith et al. 1995). Wetland functions result from the interactions among the attributes of the wetland, its watershed, the surrounding landscape (e.g., geomorphic setting, landscape position, and watershed size), the structural components of the wetland ecosystem (e.g., plants, animals, soil, water, and atmosphere), and the processes that link these structural components (e.g., overbank flooding, evapotranspiration, chemical reactions in the soil, predation, and the capture of light energy).

This rather broad definition makes it possible to identify a large number of functions for any particular regional wetland subclass. In the selection of functions, one way to deal with the large number is to think of wetland functions in

terms of a hierarchy that begins with very general functions at the highest level and becomes increasingly more specific and detailed at lower levels. In Figure 4-2, for example, element cycling is a general function attributable to wetlands. Within the context of element cycling it is possible to define more specific functions such as nutrient cycling. Within the context of nutrient cycling one could define more specific functions such as nitrogen cycling or phosphorus cycling. Within the context of nitrogen cycling it is possible to define more specific functions such as denitrification (i.e., transformation of nitrate to gaseous nitrous oxide and molecular nitrogen). Similar hierarchies exist for other categories of functions. For example, one could consider the provision of habitat for wildlife in general, for a particular group of species (e.g., amphibians, mammals, neotropical migrant birds), or for a single species (e.g., cerulean warbler, tiger salamander).

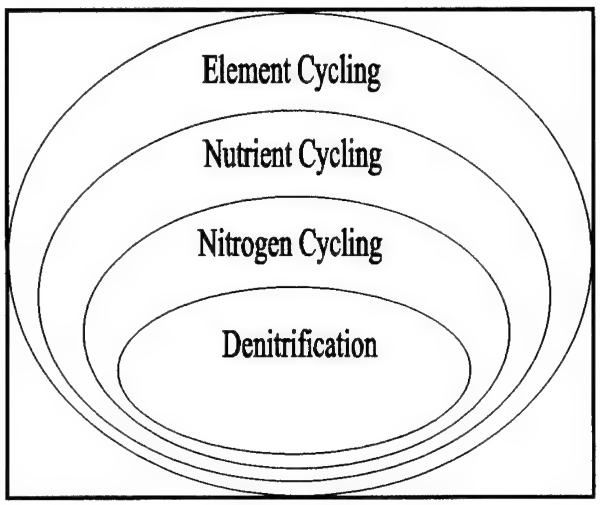

Figure 4-2. The hierarchy of wetland functions

In deciding which functions to select, the A-Team must consider the advantages and disadvantages inherent at each level of the hierarchy. Assessment models for more general functions typically require a larger number of model variables, which can reduce model sensitivity by requiring a large change in any one variable to have a noticeable effect on the overall functional index. The degree of sensitivity also depends on the nature of the aggregation equation, given that multiplicative and minimum/maximum functions can exert a controlling influence on model output regardless of the number of model variables (see "Defining Model Variables Interactions" later in this chapter). Larger numbers of variables also increase the time, effort, and expense required to collect field data with which to apply the model. General models may also be more difficult to design because of conflicts in the way that environmental variables affect different components of the function being modeled. For example, more frequent flooding may benefit amphibians but be detrimental to mammals and ground-dwelling birds. Furthermore, if a function is too general, it may be difficult to identify an appropriate independent measure of function with which to validate the assessment model.

Selecting functions at a high level of detail or specificity also has inherent problems. First is the potential for proliferation in the number of functions required to represent the range of characteristics and processes that occur in a wetland. Such proliferation can be minimized, however, if it can be assumed that a single, highly specific function (e.g., denitrification rate) is appropriate as an indicator of a broader wetland process (e.g., nutrient cycling). In deciding upon the number of functions to model, the A-Team should also consider limitations in the time and resources available for conducting a functional assessment by regulatory staff. For the HGM Approach to be a practical tool in the context of 404, it must be possible to complete the field work required for the assessment in a day or less. Certain factors such as a large or heterogeneous permit area may increase this time frame; however, experience has shown that it is possible for trained personnel at a typical site to collect the field data necessary to run assessment models for 5 to 15 functions with 10 to 25 model variables in one day. This represents a good rule of thumb when selecting functions for use in 404 or similar assessment scenarios.

If function proliferation can be constrained, the selection of more specific functions has certain practical advantages over very general functions. First, the more focused model may require fewer variables and the influence of each variable on functional capacity may be more apparent. Second, environmental factors affecting the specific function may be better understood and more thoroughly documented in the literature, requiring fewer assumptions in model development. Third, selection of an independent measure of function for model validation may be more straightforward and direct measurements of function easier to make in the field. The kinds of functions selected for regional guidebooks now under development tend to be in the midrange of the hierarchy of functions described previously (Brinson et al. 1995; Ainslie et al., in preparation Trott et al., in preparation (three guidebooks); Gilbert, in preparation; Sheehan, in preparation; Rhinehardt, in preparation; Hauer, in preparation; and Vinzant, in preparation).

Level of model resolution

Model resolution is defined as the intended accuracy and precision of the model. It is possible to develop both high-resolution and low-resolution models at any level of the hierarchy of functions described previously. Some important characteristics of low-resolution and high-resolution models are shown in Table 4-1. In general, low-resolution models are more quickly and efficiently applied, but may result in less reliable information upon which to base a decision. High-resolution models produce more reliable results, but require more time and training to apply, and require more detailed knowledge and technical input to develop. Again, A-Teams may choose to develop models in the midrange between these two extremes. Another option is to develop both low- and high-resolution versions of each model, allowing model users to select the level of resolution that is appropriate for a particular application (Schroeder and Haire 1993).

Table 4-1
Some Characteristics of Lower Resolution and Higher Resolution Models

Lower Resolution Models	Higher Resolution Models
Provide lower accuracy and precision of model output	Provide higher accuracy and precision of model output
Require fewer variables	Require more variables
Require less detailed technical literature and knowledge to develop	Require highly detailed technical literature and knowledge to develop
Rely on indirect measures and indicators of model variables	Rely on more direct measures of model variables
Use more qualitative and discrete measurement scales	Use more quantitative and continuous measurement scales
Rely more on observational sampling	Rely more on statistical sampling designs
Require less highly trained and experienced field personnel to apply	Require more highly trained and experienced field personnel to apply
Require less time and expense to perform an assessment	Require more time and expense to perform an assessment
May be easier to export to a different region without extensive modifications	May be more difficult to export to a different region without extensive modifications
Require less rigorous validation	Require more rigorous validation

Defining Wetland Functions

Once a suite of wetland functions has been selected for a regional wetland subclass, the A-Team must provide (a) a name, (b) a definition, and (c) an independent, quantitative measure of function for each function selected. Function names should be chosen carefully to avoid ambiguity and to reflect the intended function definition. For example, a wetland function named Maintain Characteristic Wildlife Community is unclear because it is not immediately obvious what is meant by a "characteristic wildlife community" or how deviations from the characteristic community would be recognized or measured. There may be several ways to rename this function so that it can be clearly defined and quantified. For example, the A-Team may decide that the diversity of wildlife species (i.e., birds, mammals, reptiles, and amphibians) in the wetland is a good general indicator of its wildlife support function. Therefore, they could rename the function Maintain Wildlife Species Diversity and define it as the capacity of the wetland to maintain the characteristic diversity of native wildlife species. Diversity could be quantified based on the Shannon-Wiener diversity index (Peet 1974) or by a simple count of wildlife species present. Alternatively, the A-Team could decide to recast the function Maintain Characteristic Wildlife Community at a different level in the hierarchy of functions, and develop separate functions for each important component of the wildlife community. This might include functions such as Maintain Diversity of Breeding Bird

Species or Maintain Density of Breeding Amphibians, for which concise definitions and quantitative measures can be identified.

Functions must be defined in a clear, concise, and quantifiable way. Unambiguous function definitions are essential to focus A-Team members and peer reviewers on the specific wetland attribute or process being modeled, to guide the selection of model variables and measures there, and to define the nature of interactions among model variables. A function definition should consist of one or two sentences that clearly identify the ecosystem attributes and processes to be modeled. For example, the Low-Gradient Riverine Regional Guidebook for western Kentucky (Ainslie et al., in preparation) defines the Temporary Storage of Surface Water function as "[t]he capacity of a riverine wetland to temporarily store and convey surface water during overbank flood events. The primary source of the surface water is normally an adjacent stream channel, but other sources can include overland flow, interflow, or direct precipitation." This definition provides clues to the attributes and processes that will need to be captured as model variables, including the factors that affect the storage capacity of the wetland and the rate at which water passes through the wetland.

The final step in function definition is to identify an independent measure of each function, along with appropriate quantitative units. For example, Ainslie et al. (in preparation) identify the independent measure of function for the Temporary Storage of Surface Water as "the volume of water stored by a wetland during a water year (i.e., m^3/yr)." Identification of an independent, quantitative measure of function is mandatory if assessment models are to be amenable to testing and validation and accepted by the scientific and regulatory communities. Assessment models are validated by comparing their output (i.e., the FCI) against the independent measure of function (e.g., a direct count of breeding bird species, or a direct measure of sediment accretion). Such comparisons are needed to evaluate model accuracy, and they provide the information needed to modify the model and improve its performance (see Chapter 7). Table 4-2 provides examples of independent, quantitative measures for a variety of potential wetland functions.

Developing the Initial Assessment Model

Conceptualizing the assessment model

After the A-Team has selected and defined a suite of functions, the next task is to conceptualize an initial assessment model for each function. Conceptualization of the assessment model requires that the A-Team (a) identify model variables that represent the structural components and processes of the wetland ecosystem and the surrounding landscape that significantly influence functional capacity, (b) define the quantitative relationship between each model variable and functional capacity, and (c) develop an equation to aggregate model variables into an FCI. The initial assessment model is a complete model that is based on the knowledge and experience of experts, the literature, and existing

Table 4-2
Potential Independent, Quantitative Measures for Selected Wetland Functions

Wetland Function	Potential Quantitative Measures
Hydrologic Functions	
Temporary Storage of Surface Water	Average volume of water stored (m^3/ha/year)
	Lag time of input and output flow peaks (days)
Subsurface Storage of Water	Volume of water absorbed (m^3/ha/year)
	Volume of available pore space (m^3/ha)
Maintenance of Base Flows	Wetland contribution to low flows (m^3/ha/deg)
Biogeochemical Functions	
Cycling of Nutrients	Net primary productivity (kg/ha/year)
	Annual turnover of detritus (kg/ha/year)
Removal of Elements and Compounds	Phosphorus retention (g/ha/year)
	Denitrification rate (g/ha/year)
	Soil denitrification enzyme activity (DEA) (g N/g/deg)
Retention of Particulates	Amount of sediment trapped (tons/ha/year)
	Sediment accretion rate (cm/year)
Export of Organic Carbon	Rate of biomass export (kg/ha/year)
Habitat Functions	
Support Native Plant Diversity	Diversity of native plant species (index, H′)
	Number of rare or endemic species (count)
Support Native Wildlife Diversity	Wildlife species richness (count)
	Number of species of forest interior birds (count)
	Density of breeding amphibians (number/ha)
Support Characteristic Invertebrate Community	Invertebrate biomass (kg/ha)
	Arthropod species richness (count)
Support Landscape/Regional Biodiversity	Number of species unique or rare in the region (count)
	Number of food web links (count)

data. The model development process is not over, however, until the model has undergone several iterations of review and revision as part of the calibration, verification, and validation phases of regional guidebook development (Chapter 1).

Selecting model variables

Sources of information that can help in identifying potential model variables include several reports that summarize information on the physical, chemical, and biological variables used in a variety of assessment methods (e.g., Canter and Hill 1979; Hays, Summers, and Seitz 1981; Hamilton and Bergersen 1984j; Adamus and Brandt 1990; Adamus et al. 1991; Simenstad, Tanner, and Thom 1991; Adamus 1992; Solomon and Sexton 1994). Model variables can also be identified from the technical literature dealing with more quantitative approaches to assessing hydrologic and biogeochemical functions (e.g., Welcomme 1979; Tiedje, Sorensen, and Chang 1981; Winter 1981; Tiedje 1982; Hammer and Kadlec 1986; LaBaugh 1986; Heliotus and DeWitt 1987; Guertin, Barten, and Brooks 1987; Brunner 1988; Kadlec 1988; Faulkner, Patrick, and Gambrell 1989; Gunderson 1989; Rosenberry 1990; Chescheir et al. 1991; and Kleiss 1996).

Existing national and regional guidebooks are another valuable source of information for identifying model variables. Before adopting a variable from another source, however, the A-Team must critically analyze the rationale given for including a particular variable and determine if it is relevant and appropriate in the context of the new regional wetland subclass. In some cases, individual model variables, or an entire model, can be adopted, particularly when both the existing model and the model being developed are for the same wetland subclass. For example, some of the model variables and assessment models for low-gradient riverine systems developed for western Kentucky might be adopted for assessing low-gradient riverine systems throughout the Lower Mississippi River Valley and the coastal plain. Rarely, however, will model variables or assessment models translate as well between regional wetland subclasses that belong to different classes (e.g., riverine wetlands to depressional wetlands).

The list of model variables garnered from published assessment models and other literature sources can be expanded by brainstorming about potential additional structural components and processes that might be important in a particular regional wetland subclass. The objective at this point is to make sure that all the important factors have been identified and not necessarily how they interact. For example, if the function under consideration is related to habitat, identify all of the factors that are critical to the survival, reproductive success, and long-term viability of the plants or animals under consideration. This might include the presence of certain plant species or other specific habitat features such as snags, mature trees, or seasonal pools. Similarly, if the function is related to hydrology, identify the factors that affect how water gets to the wetland, moves through the wetland, and leaves the wetland. Not all of the variables identified during the initial literature search and brainstorming period will necessarily be included in the assessment model.

After identifying potential model variables, the A-Team should critically review the list for redundant, irrelevant, and insensitive variables. The majority of assessment models developed for the HGM Approach to date have contained between two and six variables. This number probably represents a good rule of

thumb, but it is not a rigid requirement. As indicated previously, more detailed functions (i.e., lower in the hiearchy of functions) usually require fewer variables, whereas more general functions often require a greater number of variables. For example, a model designed to assess habitat suitability for a particular species (e.g., Bell's vireo) will probably require fewer variables than a model designed to assess an entire guild or class of organisms (e.g., all birds). If the number of variables required exceeds six or seven, consider defining two or more specific functions instead.

Another important factor to consider in reviewing variables is the range of values exhibited by a variable and its sensitivity to potential impacts. Wetlands are dynamic systems subject to change on a variety of spatial and temporal (e.g., daily, seasonal, and annual) scales. Variables that exhibit a wide range of values under relatively unaltered conditions may not be useful for detecting change resulting from either natural processes or anthropogenic impacts. Remember that in the context of 404 and similar applications, the primary use of the models is to detect changes in functional capacity that result from project impacts. The types of impacts associated with 404 include dredging, filling, levee construction, land clearing, draining, ditching, and other actions that alter hydrologic regimes and other wetland characteristics. These impacts are not subtle, and assessment models should be capable of detecting the types of changes that are likely to occur as a result of these impacts. Variables that are insensitive to the types of impacts that typically occur in the regional wetland subclass are of little use in assessing change. Here again, the knowledge and field experience of the A-Team are essential in the selection process. Finally, remember that all variables must be either directly measurable or amenable to indirect evaluation using surrogate indicators. Variables that cannot be measured either directly or indirectly are useless.

Defining model variables and measures of model variables

As with functions, after model variables have been selected they need to be defined clearly and concisely. For example, Ainslie et al. (in preparation) defines the variable "gradient" as "... the slope of the floodplain in a direction parallel to the flow of floodwater." Once model variables have been defined, the A-Team should document in writing the criteria and rationale used in selecting model variables, and discuss the specific structural component or process that each variable represents and how it influences functional capacity. The documentation should provide literature references and personal experience to support this discussion, and clearly identify assumptions and data gaps.

The next task is to determine how each model variable will be measured. Implicit in this decision is selection of the scale and units with which the measurement will be made. There are four basic scales of measurement: nominal, ordinal, interval, and ratio (Zar 1974). The nominal scale is a qualitative scale of measurement in which the variable being measured is assigned to one of two or more mutually exclusive categories that have no implied magnitude or order. For example, a certain characteristic may be identified as present or absent, or a

soil might be placed into clay, loam, sand, or peat categories. Equivalence (e.g., two soils are in the same category) is the only mathematical relation or operation that can be applied to nominal scale data (Table 4-3). The ordinal scale is also a qualitative scale of measurement in which three or more categories are ranked or ordered in relation to each other, and the numerical distance between categories is unknown. The Braun-Blanquet scale for measuring plant abundances (e.g., 0-5, 5-10,10-25, 25-50, etc.) is an example of an ordinal scale. Equivalence and order are the only mathematical relations and operations that can be applied to ordinal scale data.

Table 4-3
Permissible Mathematical Relations and Operations for Various Scales of Measurement

Scale of Measurement	Permissible Mathematical Relations or Operations			
	Equivalence	Order	Addition and Subtraction	Multiplication and Division
Nominal	*			
Ordinal	*	*		
Interval	*	*	*	*
Ratio	*	*	*	*

Interval and ratio scales are quantitative measures in which the numerical distance between categories is specified and constant. In the case of the interval scale, the origin or zero point is defined arbitrarily, whereas in the case of the ratio scale, it represents a true origin. Consequently, all measurements are made in terms of real numbers. An example of the interval scale is the Fahrenheit temperature scale in which the change in temperature between 40 and 41 deg and 50 and 51 deg is the same, but the zero point is arbitrary. Examples of the ratio scale include weight of an organism or the size of a tree in terms of diameter at breast height (dbh). The interval between units is constant, and the zero point has true meaning (i.e., no weight and no diameter). Permissible mathematical relations and operations for interval- and ratio-scale measurements include equivalence, order, addition, subtraction, multiplication, and division.

For most model variables, there will be a variety of standard sampling protocols from which the A-Team can select (Chapter 5). For example, tree basal area can be measured using a plot or plotless sampling method and reported in square meters per hectare, and frequency of flooding might be estimated using a regional curve and reported as the return interval in years. Deciding which method and scale of measurement are appropriate for collecting information about a model variable will depend on several factors. First, given a similar time and effort requirement, one should usually select a quantitative measurement rather than a qualitative one. Quantitative data can always be transformed to a qualitative scale of measurement at a later time, if deemed appropriate. However, the opposite is not true. Furthermore, models with quantitatively measured variables are more amenable to calibration and validation. Many of the variables typically included in assessment models can

be readily sampled remotely or in the field using a quantitative scale of measurement. For example, many field personnel are familiar with plot, plotless, or transect sampling methods and can easily collect vegetation data, such as basal area for woody plants and percent cover for herbaceous plants, on a quantitative scale. Whenever possible, consider using data collection methods that correspond to those already being used to collect vegetation data for the purposes of wetland delineation (Environmental Laboratory 1987).

Second, constraints of time, manpower, and technical expertise may limit the number and types of variables that can be sampled practically. For some variables, it is unlikely that a quantitative scale of measurement will be possible for technical reasons, such as prolonged sampling periods or the need for specialized equipment. For example, it is difficult to get a measure of average pH, water temperature, depth of flooding, or depth to water table because of the need for repeated samples over a long period. The rule of thumb mentioned earlier still applies. In a typical permit review situation, there is usually one or, at most, a few days available to collect field data. Any requirement to collect information over longer periods or with highly specialized equipment will result in data not being collected and the affected functions not being assessed.

Complete this step by documenting in writing the criteria and rationale used to select the sampling method and measurement scale for each model variable.

Transforming a measure into a subindex

Measures of model variables may be collected using different units and scales of measurement (i.e., nominal, ordinal, interval, or ratio). Before these variables are aggregated in a simple equation to produce an FCI, they must be transformed into a set of comparable, unitless measures (Schuster and Zuuring 1986; Smith and Theberge 1987). In the HGM Approach, the transformed measure is termed the model variable subindex (hereafter just subindex). The transformation is based on what has variously been called a value function (O'Banion 1980), scalar (Westman 1985), or a "normalization and standardization" procedure (Barbour, Stribling, and Karr 1995).

The relationship between the measure of a model variable and functional capacity, as expressed in the subindex, is initially defined by the A-Team based on their knowledge and experience, the literature, and available data. Like FCI, the subindex is an index to functional capacity, but it does not yet take into account the influence of other variables in the model. The defined relationship between measure of a variable and its subindex will be subject to review and revision when the model is calibrated using data from reference wetlands and as the verification and validation steps are completed. In defining the relationship, two factors must be remembered. First, values exhibited by a measure in reference standard wetlands must receive a subindex of 1. This is because reference standard wetlands, by definition, perform functions at the highest sustainable level concurrently across the suite of functions. Reference standard wetlands are chosen to reflect the highest level of function from among the least

disturbed wetlands in the least disturbed landscapes within a reference domain. Second, as the value of a measure deflects from the values exhibited in reference standard wetlands, the subindex must decrease along with the assumed level of functional capacity. The relationship between a measure and its subindex can take several forms depending on the scale of measurement used to define the measure. For example, Figure 4-3 illustrates the hypothetical relationship between the quantitative measure of tree basal area and functional capacity. The subindex increases linearly from a value of 0.0 (i.e., for areas with no basal area) to a value of 1.0 when the measure equals or exceeds 30 m^2/ha (i.e., values exhibited by reference standard wetlands).

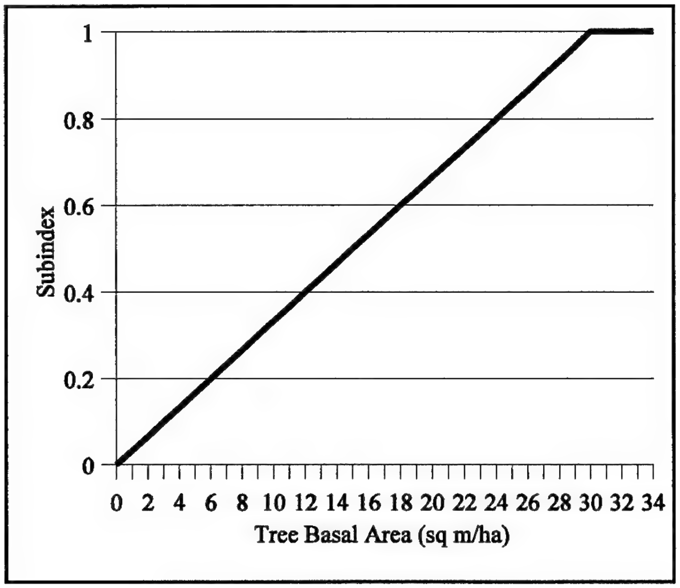

Figure 4-3. Relationship between tree basal area and functional capacity expressed as a variable subindex

Figure 4-4 illustrates a hypothetical relationship between soil type and functional capacity, perhaps for a biogeochemical function. The measure is on a nominal scale, and, thus, the subindex changes in a series of steps. The subindex ranges from a value of 0.1 for sandy soils to 1.0 for organic soils.

It is not possible for the A-Team to finalize the relationship between the measure of a variable and its subindex during conceptualization of the initial assessment model. This can be done only after the collection and analysis of reference data during model calibration (see Chapter 6). It is important, however, that the A-Team define a preliminary relationship between the measure and functional capacity using their knowledge and experience with the regional wetland subclass.

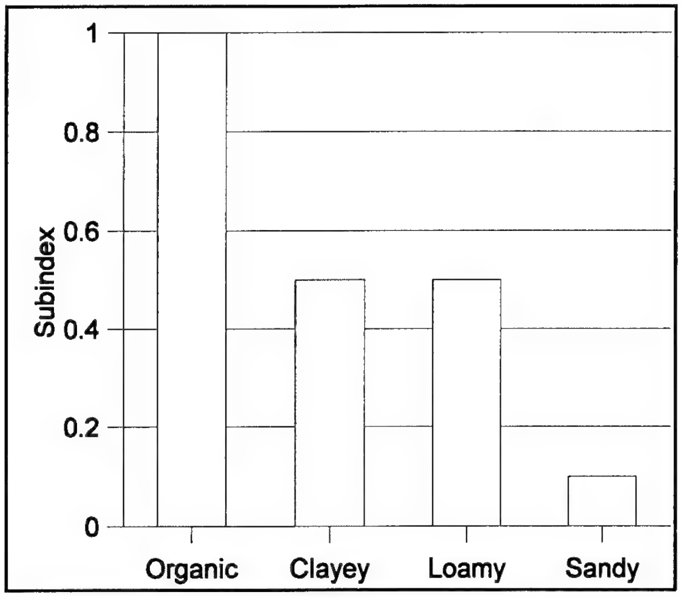

Figure 4-4. Relationship between soil type and functional capacity expressed as a variable subindex

Defining model variables interactions

The final step in conceptualizing the initial assessment model is to develop an aggregation equation for combining model variables and deriving the FCI. The objective is to capture how characteristics and processes, reflected by model variables, interact to influence the magnitude of function. There are many ways that interactions between model variables can be expressed (e.g., U.S. Fish and Wildlife Service 1981). Five basic types of interactions that may be useful in developing models for the HGM Approach are cumulative, limiting, fully compensatory, partially compensatory, and controlling. In addition, the relative influence of a variable on FCI can be modified by adjusting variable weighting factors (i.e., coefficients and exponents). In all cases, care must be taken to ensure that the calculated FCI ranges from 0 to 1.

A cumulative relationship exists when variables complement each other such that either variable alone or both in combination contributes to functional capacity. The appropriate mathematical expression is a sum, with the qualification that FCI cannot exceed 1.0 (Table 4-4). For example, a hypothetical model for Particulate Retention might use a cumulative interaction if either retention time of the water $V_{RETENTION}$ or roughness of the wetland surface V_{ROUGH}, or a combination of both variables, is sufficient to achieve optimal functional capacity (e.g., FCI = $V_{RETENTION} + V_{ROUGH}$; if sum > 1.0 then FCI = 1.0). Thus, optimal functional capacity is achieved whenever either variable equals 1.0 (even if the other variable is zero), or when their sum equals or exceeds 1.0. An FCI of zero occurs only when subindices for both variables are zero.

Table 4-4
Types of Interactions Between Model Variables and Their Mathematical Expression That May Be Useful in Developing Assessment Models for the HGM Approach

Type of Interaction	Mathematical Operation	Example
Cumulative	Addition	FCI = $V_A + V_B + V_C$; if sum > 1.0 then FCI = 1.0
Limiting	Minimum	FCI = MIN (V_A, V_B)
Fully compensatory	Maximum	FCI = MAX (V_A, V_B)
Partially compensatory	Arithmetic mean or average	FCI = $(V_A + V_B + V_C) / 3$
	Geometric mean	FCI = $(V_A \times V_B \times V_C)^{1/3}$
Controlling	Product	FCI = $V_A \times (V_B + V_C) / 2$

A limiting relationship occurs when a low value for any one variable overrides the effects of other variables; thus, the FCI is equal to the lowest of the subindex values. The appropriate mathematical expression is a minimum (Table 4-4). Limiting relationships are often used in habitat models (U.S. Fish and Wildlife Service 1981) to express the relative availability of two or more essential life requisites for a species, such as food, water, and nesting sites. Thus, overall habitat suitability is equal to the lowest of the three subindices, reflecting the life requisite that is in shortest supply.

In a compensatory relationship, a high value for one variable compensates, either in full or in part, for a lower value of another variable. The interaction is fully compensatory if the final FCI is equal to the highest of the component subindices. In this case, the appropriate mathematical expression is a maximum (Table 4-4).

A partially compensatory relationship exists when two or more variables contribute equally and independently to the level of function. Mathematical expressions used to model partially compensatory interactions include the arithmetic mean (or average) and the geometric mean. In each case, the resulting FCI lies somewhere between the extreme values of the subindices. The arithmetic mean is relatively less sensitive to subindices with low values. Therefore, when subindex values for the variables are different, the arithmetic mean returns a higher result than the geometric mean (Figure 4-5). An important difference between the two mathematical expressions is that the geometric mean returns a zero whenever *any* of the component subindices is zero, whereas the arithmetic mean returns a zero only when *all* of the subindices are zero.

A controlling relationship occurs when the presence of one environmental feature or process is critical to the performance of a function, and thus has the potential alone to control the function. The appropriate mathematical operation is a product (Table 4-4). For example, a simple model for Organic Carbon Export might contain the following aggregation equation: FCI = $V_{FREQ} \times (V_{LITTER} + V_{CWD})/2$. Carbon export is affected by the abundance of leaf litter V_{LITTER} and coarse woody debris V_{CWD}, which are grouped and averaged because they

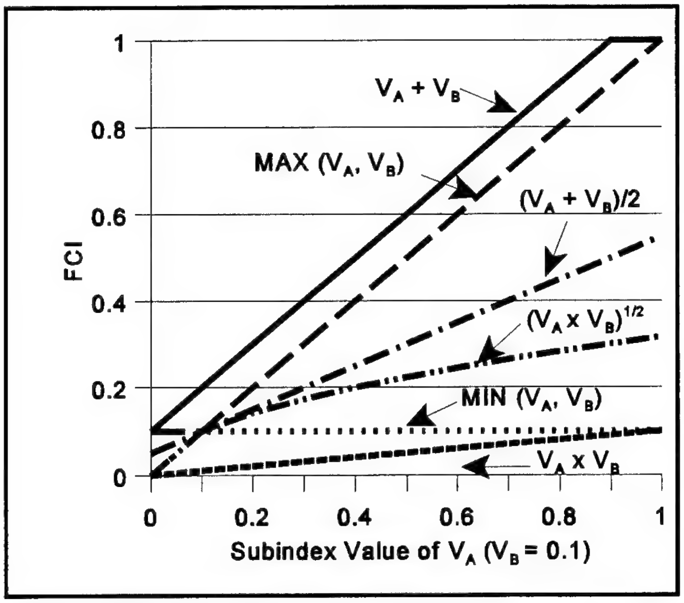

Figure 4-5. Effects of different mathematical operations in combining V_A and V_B. In all cases, the value of V_B is fixed at 0.1, while V_A varies between 0 and 1.0

contribute equally and independently to the availability of material for export. However, carbon export cannot occur unless floodwaters scour the site regularly. Combining frequency V_{FREQ} by means of a product reduces FCI to zero if the site does not flood, despite high values of the other variables.

A final way to affect the role of an individual variable in the calculation of FCI is to modify its weight in the aggregation equation. This is done by adjusting its coefficient (e.g., in a sum or arithmetic mean) or its exponent (e.g., in a geometric mean). For example, consider the following simple aggregation equation: FCI = $(V_A + V_B + V_C) / 3$. To increase the influence of V_A in the calculation of FCI, one could increase its coefficient to two, remembering to increase the divisor so that FCI does not exceed one. Thus the equation becomes FCI = $(2V_A + V_B + V_C) / 4$. For a geometric mean, the equivalent procedure is to increase the exponent of a variable. For example, the influence of V_A in the equation FCI = $(V_A \times V_B \times V_C)^{1/3}$ can be increased by squaring V_A. The modified equation becomes FCI = $(V_A^2 \times V_B \times V_C)^{1/4}$.

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14. ABSTRACT

In the Hydrogeomorphic (HGM) Approach, assessment models are a simple representation of the functions performed by wetland ecosystems. The purpose of an assessment model is to estimate the magnitude at which a wetland performs a function relative to similar wetlands in the region. Model variables represent attributes and processes of the wetland ecosystem and the surrounding landscape that influence the ability of the wetland to perform a function. They are quantitatively measured or qualitatively estimated in the field using a standard sampling protocol. This chapter introduced the initial steps in the development of assessment models under the HGM Approach. The initial steps considered here include (1) selection and definition of wetland functions, (2) identification of model variables and field measures, and (3) construction of aggregation equations for deriving functional indices. Other chapters in this volume consider other steps related to the development of assessment models including identification of reference wetlands (Chapter 3), collection and management of reference data (Chapter 5), analysis of reference data and calibration of assessment models (Chapter 6), and verification and validation of assessment models (Chapter 7)

15. SUBJECT TERMS

Assessment models	HGM	Model variables	Wetland assessment
Functional assessment	Hydrogeomorphic Approach	Variable subindices	Wetland functions

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